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Effect of Charcoal and Humic Acid on Vegetative Growth, Flowering and Fruit Quality of Almond Trees

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ABSTRACT

The present research was investigation during two successive seasons of 2021 and 2022 at private rain-fed almond grove at Marsa Matrouh Governorate, Egypt. Twelve years old almond trees budded on Bitter almond rootstock grown in sandy loam soil. To study the effect of charcoal as soil applications at 500, 1000 and 1500g/tree/year and humic acid as soil applications at 25, 50 and 75g/tree/year as well as their combinations on vegetative growth, leaf nutrients content and productivity. The obtained results showed that applications of charcoal, humic acid and their combinations induced a pronounced improvement in vegetative growth characteristics; shoot length increase, number of shoots/branch, number of leaves/shoot, leaf area and leaf chlorophyll content. Moreover, these applications enhancement the nutritional status of trees leading to significant increases in fruit set, yield as well as an improvement in fruit quality. Finally, it is preferable to add charcoal at 1500g/tree/year plus humic acid at 75g/tree/year as a soil application with winter horticultural practices before the rains fall to enhance vegetative growth characteristics, leaf nutrients content, yield and kernel quality of almond trees under those conditions.

Keywords: Almond tree, charcoal, humic acid, vegetative growth characteristics, leaf nutrients content, yield, kernel quality

1. Introduction

Almond *(Prunus dulcis* (Miller) D.A. Webb) is a nut tree in the family Rosaceae grown in Mediterranean climate. Moreover, it is relatively drought resistant (Karimi *et al*., 2013 and Palasciano *et al*., 2014). Almond cultivation in both north eastern and western coast, special Marsa Matrouh condition, Egypt and it depend on rain-fed irrigation and sometimes need supplementary irrigation if necessary. Furthermore, those rain-fed almond crops supported growers to stabilize in this rain-fed coastal area. In mid-November trees receive the winter horticultural practices before the rains fall, where almond trees fertilized with organic manure and chemical fertilizers and trees does not receive any fertilization after that. However, almond trees under rain-fed irrigation in Egypt did not obtain enough attention by researchers. Under rainfed conditions in Egypt, almond trees suffering from a lack of nutrients and this appears on the growth, productive and fruit quality. In additions, the horticultural practices development in almond groves is necessary for those rain-fed conditions to improve almond production. So adding mineral nutrients is necessary. In this respect, many researchers have worked on added charcoal to field crops, but there is a scarcity of researchers who used it in fruit trees especially almond under rain-fed conditions. Recently, charcoal used as soil conditioner which promotes plant growth, and it may improve soil physical properties, fertility, and biological conditions (Ishii and Kadoya, 1994).

Charcoal is an organic material composed largely of carbon and it produced via the pyrolysis of C-based also it is described as a soil conditioner. It has other defined such as coal, ash, carbon, char and biochar but biochar is a charcoal has been pyrolysed in a zero or low oxygen environment (Verheijen *et al*., 2009). It improve soil properties, soil aeration, water holding capacity and nutrient retention as well as it may lead to decreased nutrient leaching (Abou Yuossef, and Abou Hashem, 2005 and Downie *et al*., 2009). Charcoal application to soil lead to higher nutrient retention and nutrient availability

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moreover, it increased the ratio of uptake to all nutrients (Glaser *et al*., 2002 and Lehmann *et al*., 2003). Tryon (1948) found that the addition of charcoal in sandy soil increased the available moisture from 18% to 45% and it increased water retention. In addition, wood ashes amendments application increases the growth and yield of agricultural crops in the greenhouse and field (Vance, 1996).

Charcoal, biochar and wood ash increased soil pH and EC may be due to its alkaline nature when used as a soil additive may contribute to raise pH (Major, 2010; Novak *et al*., 2009). Orman (2012) and El-Wakeel and Mansour (2014) found that wood ash mixed with sulfur application decreased soil pH under our soil condition in Egypt. It notice that no researcher worked on charcoal application on almond especially under rainfed conditions. Lehmann *et al*. (2003) found that the application of charcoal reduced leaching of applied mineral fertilizer nitrogen and increased efficiency of nutrients applied. Steiner *et al*. (2007) indicated that organic manure with charcoal application improved crop production and it increment nutrients content in the rooting zone of crops. Sumedrea *et al*. (2013) indicated that 10kg charcoal/m^2 at 0.0 – 40.0 cm depth soil application increased number of flower buds/tree and yield as compared with untreated control of apple trees. El-Wakeel and Mansour (2014) indicated that wood ash at 1000g/tree/year combined with sulfur at 500g/tree/year improved leaf area, leaf chlorophyll and leaf dry matter moreover, wood ash at 500g/tree/year plus with sulfur at 500g/tree/year increased leaf N, P, K, Ca, Mg, Fe, Mn and Zn content of navel orange trees. Moreover, biochar applications may result in bigger, healthier fruits and nuts (Kelpie, 2015). El-Merghany *et al*. (2021) conducted that Biochar application 3kg/tree gave the highest yield and fruit quality than control trees, and it improved leaf N, P, K, Ca and Mg contents of Hayany date palm. The research is also directed to the use one of the other natural sources, such as humic acid, which is environmentally friendly (Abourayya *et al*., 2020).

Humic acid is a natural material improves the soil physical, chemical and biological properties, and increases the ability of the soil to retain water (Biondi *et al*., 1994). It increases the tolerance of plants to environmental stress (Aydin, *et al*., 2012 and Mazhar, *et al*., 2012). It has positive effects on plant growth that are similar to the effects of growth regulators like IAA, GA and cytokine (O'Donnell, 1973; Hoany and Tichy, 1976 and Fawzi *et al*., 2007). It leads to an increment in the growth of the root system and an increase in the nutrients absorption by the plant (Sajadian and Hokmabadi, 2015). It can be used to reduce the amounts of mineral fertilization (Mohamed and Ashraf, 2016).

Humic acid improved flowering, fruit set and fruit quality in a number of fruit trees (Fernández-Escobar *et al*., 1996 on olive trees; Celik *et al*., 1995 and Ferrara and Brunetti, 2010 on grape). Mayi *et al*. (2014) indicated that humic acid application increased leaf N, P, K and Zn content of olive trees. But a little has been reported in this subject of almond. Eisa *et al*. (2016) mentioned that humic acid foliar application improved vegetative growth and leaf macro and micro-elements content of almond young trees. Abourayya *et al*. (2020) reported that 30g humic acid/young tree soil application improved the vegetative growth and nutritional status of Nonpareil almond young trees under Nubaria conditions. Shaymaa *et al*. (2022).illustrated that 200 ml/l humic acid foliar application on April 25th and May 27th increased stem length, chlorophyll, leaf area, and leaf N, P, K and B of almond seedlings.

This work was conducted to study the effect of adding soil applications of charcoal and humic acid as well as their combinations with the winter horticultural practices before the rains fall, on vegetative growth characteristics, nutrients status and production of almonds under rain-fed conditions, Egypt.

2. Materials and Methods

This investigation was carried out during two consecutive seasons of 2021 and 2022 on healthy "Non-pareil" almond trees *(Prunus dulcis* (Miller) D.A. Webb) of about 12 years old, budded on Bitter almond rootstock and planted at 7x7m apart. Trees were grown on sandy loam soil under rainfed conditions at private almond grove at Marsa Matrouh Governorate, Egypt. Some properties of the experimental soil are shown in Table (1).

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Table 1: Analysis of experimental soil.

Soil Depth (cm)		Texture Class		pH Soil past		E.Ce (dSm^{-1})	
0-30		Sand loam		7.8		1.0	
30-60		Sand loam		7.5		0.7	
Soluble cations (meq/l)				**Soluble anions (meq/l)**			
Ca^{++}	**K^{+}**	**Na^{+}**	**Mg^{++}**	**Cl^{-}**	**$SO_4^{=}$**	**HCO_3^{-}**	**$CO_3^{=}$**
3	0.5	5.5	1	5	3	2	-
2	0.16	4.04	0.8	3.7	2.3	1	-

Weather data of almond grove, Marsa Matrouh Governorate, Egypt during 2020, 2021 and 2022 seasons showed in Table 2, from Central Laboratory for Agriculture Climate, Agricultural Research Center, Egypt.

Table 2: Average of temperature, relative humidity, and amount of precipitation of almond grove during 2020, 2021 and 2022 seasons.

	2020-2021				2021-2022		
Months	**Average Temperature (°C)**	**Average Relative Humidity (%)**	**Precipitation (mm)**	**Months**	**Average Temperature (°C)**	**Average Relative Humidity (%)**	**Precipitation (mm)**
November	19.91	71.95	7.0	**November**	20.99	66.83	10.60
December	17.07	69.15	9.50	**December**	16.33	64.95	25.30
January	15.45	72.23	130.70	**January**	13.33	72.39	124.60
February	14.83	72.48	58.40	**February**	13.83	73.65	36.80
March	15.03	73.34	20.5	**March**	13.51	73.71	55.30
Total	16.46	71.83	226.1	**Total**	15.60	70.31	252.60

Central Laboratory for Agriculture Climate, Agricultural Research Center, Egypt.

Forty trees healthy, nearly in shape and size and productivity as well as received the same horticulture practices, were subjected to eight treatments as: control (without charcoal or humic acid), charcoal as soil application at 500 g/tree/year, charcoal as soil application at 1000 g/tree/year, charcoal as soil application at 1500 g/tree/year, humic acid as soil application at 25 g/tree/year, humic acid as soil application at 50 g/tree/year, humic acid as soil application at 75 g/tree/year and soil application of charcoal at 1500 g/tree/year + humic acid at 75 g/tree/year. Rates of charcoal and/or humic acid applied with a mixture of sheep manure and chemical fertilizers in winter horticulture practices as soil applications. The main proprieties of charcoal were summarized in Table (3).

Table 3: Analysis of charcoal

pH Soil past		E.Ce (dSm^{-1})		Organic matter (%)		N (%)	P_2O_5 (%)
8.0		3.26		2.00		1.00	0.10
Soluble cations (ppm)				**Soluble anions (ppm)**			
Ca^{++}	**K^{+}**	**Na^{+}**	**Mg^{++}**	**Cl^{-}**	**$SO_4^{=}$**	**HCO_3^{-}**	**$CO_3^{=}$**
7.337	17.369	50.259	7.836	64.014	7.51	11.277	-

The experiment was designed as a randomized complete block design with five replicates for each treatment and each replicate was represented by one trees. In mid-November of 2020 and 2021 seasons, trees receive the winter horticultural practices before the rains fall, where almond tree (each tested tree) fertilized with a mixture of sheep manure fertilizer (20 kg/tree sheep manure) mixed with chemical fertilizers (1 kg/tree super calcium phosphate (45% P_2O_5) + 250 g/tree potassium sulfate + 500 g/tree sulfur (95 % S) + 250 g/tree sulfur coated urea (36.5% urea and 16% S). Chemical analysis of the tested sheep manure was presented in Table (4).

Table 4: Chemical analysis of sheep manure

N(%)	P(%)	K (%)	Ca (%)	Mg(%)	Fe ppm	Mn ppm	Zn ppm	Organic matter content (%)
1.71	0.61	0.61	0.33	0.38	871	160	15	50.10

A Mixture of sheep manure and chemical fertilizers as well as charcoal and humic acid applied in the two trenches (100 cm length x 30 cm width x 40 cm depth) were digged on both sides of the tree at 1 m apart from the tree trunk and covered with trench soil. The treated trees were evaluated through the following determinations:

2.1. Vegetative growth

In early of both seasons, four branches, nearly uniform in diameter and length were labeled on different treated tree directions. Twenty developing vegetative shoots per tree (five shoots on every branch) were tagged to determine the mean increase in shoot length. At the harvest time the average number of new shoots per branch were counted and recorded. Moreover, leaves of tagged shoots were counted and the increase in their number was determined and recorded.

Moreover, leaf area; after harvest time, twenty mature leaves [the third one from the base of the tagged, non-fruiting, shoots] were collected for estimating leaf area using area meter (model cl-203, USA). Leaf chlorophyll content was determined by Minolta chlorophyll meter SPAD-502.

2.2. Leaf nutrient contents

Thirty leaves from each replicate were taken from non-fruiting shoots in both seasons, cleaned and dried at 70^o and digested according to Chapman and Pratt (1961). Nitrogen was determined by the micro-kjeldahl method Pregl (1945). Phosphorus percentage was determined calorimetrically using spectrophotometer 882 UV at the wave length of 660 nm according to Matt (1968). Potassium was determined by flame photometer according to Jackson (1958). Fe, Mn and Zn were determined by Atomic Absorption (model GBC 932).

2.3. Fruit set percentage and yield (kg/tree)

The number of fruitlets per cluster was counted after three weeks of full bloom to determine the initial number of set fruitlets. The initial fruit set was calculated as a percentage. In each season, at harvest time (August, 15th), yield (kg/tree) was weighed and recorded.

2.4. Fruit quality:

Twenty ripen fruits were taken at harvest when the almonds were found to be ripe, at least 80% open hull from each treated tree. The fruit separated to obtain the almond kernels then the determination of the following physical properties i.e. kernel weight (g), kernel length (cm), and kernel width (cm).

2.5. Statistical analysis

The obtained data in 2021 and 2022 seasons were subjected to analysis of variance according to Clarke and Kempson (1997). Means were differentiated using the Range test at the 0.05 level (Duncan, 1955)

3. Results and Discussion

3.1. Vegetative growth characteristics (Shoot length increase, No. of shoots/branch, No. of leaves/shoot, leaf area and leaf chlorophyll content)

Tables, 5 and 6 illustrates that all tested treatments induced significant differences in shoot length increase, no. of shoots/branch, no. of leaves/shoot, leaf area and leaf chlorophyll content of almond trees as compared with control trees in both seasons. Moreover, increasing charcoal and/or humic acid application rates induced a progressive enhancement of shoot length increase, no. of shoots/branch, no. of leaves/shoot, leaf area and leaf chlorophyll content of almond trees as compared to control treatment in both seasons. Charcoal rates surpassed humic acid to enhance of the studied vegetative growth characteristics. Generally, soil application of charcoal at 1500g/tree/year plus humic acid at 75g/tree/year gave the highest positive effect on vegetative growth characteristics; shoot length increase, no. of shoots/branch, no. of leaves/shoot, leaf area and leaf chlorophyll content of almond trees in both seasons.

Table 5: Effect of charcoal and humic acid as soil application on shoot length increase, number of shoots and number of leaves/shoot of almond trees during 2021 and 2022 seasons.

Treatments	Shoot length increase (cm)		No. of shoots/branch		No. of leaves / shoot	
	2021	2022	2021	2022	2021	2022
Control	25.6 F	30.0 F	6.3 G	9.0 E	16.0 E	19.0 F
Charcoal at 500g/tree	33.0 DE	35.6 D	9.0 E	12.0 CD	18.0 D	23.0 D
Charcoal at 1000g/tree	35.3 BC	37.0 C	11.0 D	13.0 C	21.0 BC	25.0 C
Charcoal at 1500g/tree	37.3 AB	40.0 B	14.0 B	14.6 B	22.0 B	27.0 B
Humic acid at 25g/tree	31.3 E	32.0 E	7.6 F	10.6 D	17.0 DE	20.0 EF
Humic acid at 50g/tree	32.0 DE	35.0 D	11.0 D	12.0 CD	18.0 D	21.0 E
Humic acid at 75g/tree	34.0 CD	37.0 C	12.0 C	13.0 C	20.0 C	25.0 C
1500g Charcoal + 75g humic acid /tree	38.3 A	42.0 A	15.0 A	16.3 A	24.0 A	30.0 A

Means followed by the same letter (s) within each column are not significantly different at 5% level.

The enhancement effect of charcoal on vegetative growth characteristics may be attributed that charcoal improve soil properties, soil aeration, water holding capacity and nutrient retention as well as it may lead to decreased nutrient leaching (Abou Yuossef, and Abou Hashem, 2005 and Downie *et al*., 2009). Charcoals increased the ratio of uptake to all nutrients (Glaser *et al*., 2002 and Lehmann *et al*., 2003). Tryon (1948) found that the addition of charcoal in sandy soil increased the available moisture from 18% to 45% and it increased water retention, and this stimulated the growth and improved utilization of water. That reflected on improvement in leaf area and leaf chlorophyll content. The obtained results regarding the effect of charcoal application on vegetative growth characteristics are in harmony with the findings of El-Wakeel and Mansour (2014) they mentioned that wood ash at 1000g/tree/year combined with sulfur at 500g/tree/year improved leaf area, leaf chlorophyll of navel orange trees.

Table 6: Effect of charcoal and humic acid as soil application on leaf area and leaf chlorophyll content of almond trees during 2021 and 2022 seasons.

Treatments	Leaf area (cm^2)		Chlorophyll	
	2021	2022	2021	2022
Control	6.31 E	6.16 E	35.15 F	33.62 F
Charcoal at 500g/tree	9.83 CD	10.08 CD	44.10 C	42.65 C
Charcoal at 1000g/tree	12.16 AB	12.00 AB	47.01 B	45.66 BC
Charcoal at 1500g/tree	11.25 ABC	12.25 AB	48.67 AB	47.67 B
Humic acid at 25g/tree	7.88 DE	9.00 D	37.09 EF	35.67 EF
Humic acid at 50g/tree	8.08 DE	10.25 CD	38.10 DE	37.64 DE
Humic acid at 75g/tree	10.25 BC	11.16 BC	40.23 D	39.32 D
1500g Charcoal + 75g humic acid/tree	12.75 A	13.67 A	50.08 A	51.30 A

Means followed by the same letter (s) within each column are not significantly different at 5% level.

The improvement of humic acid on vegetative growth characteristics may be attributed that application of humic acids exerts a direct effect on enzymatic activities, membrane permeability and an indirect effect mainly by changing the soil structure, increases soil aeration, and drainage (Biondi *et al*., 1994). Humic acid enhances cell division and enlargement (Mehran *et al*., 2013). Also, it has positive effects on plant growth that are similar to the effects of growth regulators like IAA, GA and cytokine (O'Donnell, 1973; Hoany and Tichy, 1976 and Fawzi et. al., 2007) that lead to improve vegetative growth characteristics. The obtained results regarding the effect of humic acid application on vegetative growth characteristics go in line with the findings of Eisa *et al*. (2016) they mentioned that humic acid foliar application improved vegetative growth of almond young trees. And Abourayya *et al*. (2020) found that 30g humic acid/young tree as a soil application improved the vegetative growth of Nonpareil almond young trees under Nubaria conditions. On the other hand, Shaymaa *et al*. (2022) mentioned that 200 ml/l humic acid foliar application on April 25th and May 27th increased stem length, chlorophyll and leaf area of almond seedlings. The obtained results regarding the effect of interaction between charcoal and humic acid on vegetative growth characteristics are in harmony with the findings of Ehsan *et al*. (2020) found that application of biochar provided with humic acid improved vegetative growth of Calendula (*Calendula officinalis* L.). Furthermore, Abdelrasheed *et al*. (2021) found that application of biochar + K-humate improved vegetative growth of onion and it substantially reduced the harmful impacts of deficient irrigation.

3.2. Leaf nutrient contents

Tables, 7 and 8 indicates that all tested treatments significantly increased leaf nutrients content of almond trees as compared with the control treatment in both seasons of study. However, charcoal at 1500g/tree/year supplemented with humic acid at 75g/tree/year treatment recorded the highest values in this respect. On the other hand, soil application of charcoal at 1500g/tree/year plus humic acid at 75g/tree/year proved to be the most efficient treatment in this respect. Other treatments induced an intermediate values in this concern. On the other hand, the control treatment recorded the lowest values in both seasons.

Table 7: Effect of charcoal and humic acid as soil application on leaf N, P and K content of almond trees during 2021 and 2022 seasons.

Treatments	N (%)		P (%)		K (%)	
	2021	2022	2021	2022	2021	2022
Control	1.78 E	1.81 D	0.136 D	0.138 E	1.29 E	1.37 E
Charcoal at 500g/tree	1.82 DE	1.85 C	0.136 D	0.142 D	1.34 D	1.40 D
Charcoal at 1000g/tree	1.83 CD	1.88 B	0.142 C	0.144 CD	1.39 BC	1.41 D
Charcoal at 1500g/tree	1.85 CD	1.89 B	0.145 B	0.146 BCD	1.41 AB	1.44 BC
Humic acid at 25g/tree	1.83 CD	1.87 BC	0.139 CD	0.144 CD	1.41 AB	1.42 CD
Humic acid at 50g/tree	1.86 BC	1.89 B	0.140 C	0.148 ABC	1.38 BCD	1.45 BC
Humic acid at 75g/tree	1.89 AB	1.90 B	0.146 B	0.149 AB	1.42 AB	1.46 B
1500g Charcoal + 75g humic acid /tree	1.93 A	1.98 A	0.153 A	0.152 A	1.44 A	1.50 A

Means followed by the same letter (s) within each column are not significantly different at 5% level.

Table 8: Effect of charcoal and humic acid as soil application on leaf Fe, Mn and Zn content of almond trees during 2021 and 2022 seasons.

Treatments	Fe (PPM)		Mn (PPM)		Zn (PPM)	
	2021	2022	2021	2022	2021	2022
Control	180.0 F	188.3 E	107.3 C	111.6 D	26.0 E	35.0 D
Charcoal at 500g/tree	198.3 E	215.0 D	120.0 AB	120.0 BC	30.3 C	41.0 C
Charcoal at 1000g/tree	217.0 CD	224.0 C	121.6 AB	122.0 AB	33.0 B	44.0 BC
Charcoal at 1500g/tree	231.0 AB	238.6 B	123.0 AB	123.0 AB	36.0 B	47.0 B
Humic acid at 25g/tree	205.0 DE	223.0 C	119.0 B	116.0 CD	38.0 DE	40.6 C
Humic acid at 50g/tree	222.3 BC	230.0 C	121.6 AB	120.0 BC	30.0 CD	42.0 C
Humic acid at 75g/tree	235.3 AB	241.0 B	124.6 AB	123.0 AB	39.0 A	48.0 AB
1500g Charcoal + 75g humic acid /tree	243.6 A	249.3 A	126.0 A	126.0 A	41.0 A	52.0 A

Means followed by the same letter (s) within each column are not significantly different at 5% level.

The enhancement effect of charcoal on leaf nutrients content may be attributed to the fact that charcoal have beneficial effect on soil physical properties, fertility, and biological conditions (Ishii and

Kadoya, 1994). It increasing water holding capacity and nutrients retention as well as it may lead to decreased nutrient leaching (Abou Yuossef, and Abou Hashem, 2005), moreover, it increased the ratio of uptake to all nutrients (Glaser *et al*., 2002 and Lehmann *et al*., 2003). Tryon (1948) found that the addition of charcoal in sandy soil increased the available moisture from 18% to 45% and it increased water retention. That reflected on enhanced the uptake of nutrients. Moreover, Steiner *et al*. (2007) mentioned that organic manure with charcoal application increment nutrients content in the rooting zone of crops. The obtained results regarding the effect of charcoal on leaf nutrients content go in line with the findings of El-Wakeel and Mansour (2014) on navel orange trees and El-Merghany *et al*. (2021) on date palm. The improvement of humic acid on leaf nutrients content may be attributed that application of humic acid stimulates the absorption of nutrients through stimulating root growth and increases the rate of absorption of mineral ions on root surfaces as well as their penetration into the cells of the plant tissue (Biondi *et al*., 1994). Also, humic acid has similar effect like cytokinin and gibberellin on olive and pear trees (Fawzi *et al*., 2007). Moreover, humic acid have similar effect like IAA in plants (O'Donnell, 1973). The obtained results regarding the effect of humic acid application on leaf nutrients content are in harmony with the findings of Mayi *et al*. (2014) they indicated that humic acid application increased leaf N, P, K and Zn content of olive trees. Shaymaa *et al*. (2022) illustrated that 200 ml/l humic acid foliar application on April 25th and May 27th increased leaf N, P, K and B of almond seedlings. The obtained results regarding the effect of interaction between charcoal and humic acid on leaf nutrients content are in harmony with the findings of Madhavi *et al*. (2017) on maize. They mentioned that biochar at 7.5 t/ha and humic acid at 30kg/ha as a soil application enhanced leaf nutrients content of maize. Moreover, application of biochar provided with humic acid induced a positive effect on nutrient plant status of Calendula plants (Ehsan *et al*., 2020).

3.3. Fruit set percentage and yield (kg/tree)

Table 9, shows that all tested applications gave the highest positive effect on fruit set percentage and yield as compared with the control treatment in both seasons of this study. On other hand, soil application of charcoal at 1500g/tree/year supported with humic acid at 75g/tree/year produced the highest fruit set percentage (29 and 28%) against the control treatment (19 and 21%) in both seasons, respectively. Generally, soil application of charcoal at 1500g/tree/year supplemented with humic acid at 75g/tree/year gave the highest yield (4.10 and 4.30 kg/tree) against the control treatment (2.05 and 2.23 kg/tree) in both seasons, respectively. Other treatments induced an intermediate values in this respect.

Table 9: Effect of charcoal and humic acid as soil application on fruit set percentage and yield of almond trees during 2021 and 2022 seasons.

Soil application treatments	**Fruit set (%)**		**Yield (Kg/tree)**	
	2021	**2022**	**2021**	**2022**
Control	19.0 F	21.0 E	2.05 E	2.23 E
Charcoal at 500g/tree	26.0BCD	25.0 C	3.16 BCD	3.93 BC
Charcoal at 1000g/tree	27.0ABC	26.6 AB	3.30 BC	3.96 ABC
Charcoal at 1500g/tree	28.0 AB	27.0 AB	3.40 B	4.06 AB
Humic acid at 25g/tree	23.0 E	23.0 D	2.90 D	3.00 D
Humic acid at 50g/tree	24.0 DE	25.0 C	3.00 CD	3.66 C
Humic acid at 75g/tree	25.6 CD	25.6 BC	3.10 BCD	3.70 C
1500g Charcoal + 75g humic acid/tree	29.0 A	28.0 A	4.10 A	4.30 A

Means followed by the same letter (s) within each column are not significantly different at 5% level.

The enhancement of charcoal on fruit set percentage and yield may be attributed that charcoal enhancement leaf chlorophyll content and that promotes photosynthesis (El-Wakeel and Mansour, 2014). On the other hand, it enhances plant root uptake and improved leave nutrients content (Vance, 1996) and that lead to increase fruit set percentage and fruit yield. The obtained results regarding the effect of charcoal on fruit set percentage and yield are in harmony with the findings of Sumedrea *et al*. (2013) on apple trees; Kelpie (2015) on nut trees and El-Merghany *et al*. (2021) on data palm. The improvement of humic acid application on fruit set percentage and yield may be attributed that humic acids have similar effect like auxins, (O'Donnell, 1973) and increasing nutrient uptake as well as increase in leaf chlorophyll which leads to increase carbohydrates contents. These lead to improve fruit set percentage and yield. On the other hand, humic acid improved growth parameters and accumulation of all the macro and microelement in the fruit (Fernández-Escobar *et al*., 1996). Those results were associated to enhancement yield. The obtained results regarding the effect of humic acid on fruit set percentage and yield go in line with the findings of Fernández-Escobar *et al*., 1996 on olive trees; (Celik *et al*., 1995 and Ferrara and Brunetti, 2010 on grape). The obtained results regarding the effect of interaction between charcoal and humic acid on leaf nutrients content are in harmony with the findings of Madhavi *et al*., (2017) on maize. They mentioned that biochar at 7.5 t/ha and humic acid at 30 kg/ha as a soil application produced high productivity of seed yield of Maize. On the other hand, Abdelrasheed *et al*. (2021) found that application of biochar + K-humate gave higher onion productivity and it reduced the harmful impacts of deficient irrigation.

3.4. Fruit quality

Table 10, indicates that all tested treatments produced statistically positive effect on kernel weight, kernel length and kernel width as compared with the control of both seasons. However, soil application of charcoal surpassed of humic acid application in improving kernel quality. And the increasing charcoal and/or humic acid application rates exerted a progressive improvement of kernel quality. Generally, soil application of charcoal at 1500g/tree/year supplemented with humic acid at 75g/tree/year proved to be the most efficient treatment in this respect. Other treatments induced an intermediate values in this concern. On the other hand, the control treatment recorded the lowest values in both seasons.

The enhancement effect charcoal on fruit quality may be attributed that charcoal promotes photosynthesis by improving leave chlorophyll content and the assimilated transport of the carbohydrates to the storage organs, and increased net photosynthetic rate, that lead to enhance plant root uptake and improved leave nutrients content (Vance, 1996; El-Wakeel and Mansour, 2014 and Kelpie, 2015), that reflected on improved fruit quality.

Table 10: Effect of charcoal and humic acid as soil application on kernel weight, kernel length and kernel width of almond trees during 2021 and 2022 seasons.

Soil application treatments	Kernel weight (g)		Kernel length (cm)		Kernel width (cm)	
	2021	2022	2021	2022	2021	2022
Control	1.00 E	1.12 F	2.06 F	2.10 F	1.05 F	1.13 F
Charcoal at 500g/tree	1.48 C	1.50 CD	2.57 D	2.54 C	1.49 C	1.49 C
Charcoal at 1000g/tree	1.59 B	1.58 C	2.72 C	2.66 B	1.58 B	1.54 BC
Charcoal at 1500g/tree	1.62 B	1.72 B	2.99 B	2.70 B	1.61 AB	1.59 B
Humic acid at 25g/tree	1.25 D	1.32 E	2.38 E	2.38 E	1.21 E	1.24 E
Humic acid at 50g/tree	1.27 D	1.35 E	2.40 E	2.44 DE	1.38 D	1.38 D
Humic acid at 75g/tree	1.31 D	1.43 DE	2.45 E	2.46 D	1.38 D	1.40 D
1500g Charcoal + 75g humic acid /tree	1.87 A	1.90 A	3.16 A	2.90 A	1.66 A	1.67 A

Means followed by the same letter (s) within each column are not significantly different at 5% level.

The obtained results regarding the effect of charcoal on fruit quality are in harmony with the findings of El-Wakeel and Mansour (2014) on navel orange trees and Kelpie (2015) on nut trees. El-Merghany *et al*. (2021) on date palm. The improvement of humic acid application on fruit quality may be attributed that humic acids enhance cell division and enlargement (Mehran *et al*., 2013). It has similar effect like IAA, cytokining and gibberellin (O'Donnell, 1973; Hoany and Tichy, 1976 and Fawzi et. al., 2007). And it increased nutrient uptake as well as increased leaf chlorophyll content (Shaymaa *et al*., 2022). That led to increased carbohydrates content and caused enhancement of fruit quality. The obtained results regarding the effect of humic acid on fruit quality go in line with the findings of Fernández-Escobar *et al*. (1996) on olive trees and Ferrara and Brunetti (2010) on grape.

Briefly, under similar conditions, resulted showed that increasing charcoal and/or humic acid application rates induced a progressive enhancement of the studied vegetative growth, leaf nutrients content, yield and fruit quality. Consequently, it is preferable to apply charcoal at 1500g/tree/year plus humic acid at 75g/tree/year as a soil application with winter horticultural practices before the rains fall to enhance vegetative growth parameters, leaf nutrients content, yield and fruit quality of almond.

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